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Evaluation of Patient with Myocardial Infarction Using Isoenergy Contour Maps of Three-Dimensional Magnetocardiograms

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Abstract

A SQUID magnetometer system with three-dimensional(3-D) second-order gradiometer was used to measure the magnetocardiograms(MCG) for the normal subject and the patient with myocardial infarction (MI). In order to discuss the activities of the heart between the normal subject and the patient with MI, we have presented the isoenergy contour maps to evaluate the spatial energy distribution (SED) of the QRS complex at different scale. Being different from the normal subject, the patient with MI represented different the pattern of the SED in various frequency band for the ST segment of the QRS complexof *Bx*, *By*, and *Bz* components. It is helpful to evaluate the patient with MI using the isoenergy contour maps of 3-D MCG.

Keyword: 3-D SQUID gradiometer, MCG, the QRS complex, isoenergy contour map, spatial energy distribution

1. Introduction

It has been noticed that the high frequency components of the QRS complex are helpful in clinical diagnosis. In particular, the ventricular late potential(LP) is at risk of ventricular arrhythmias and sudden cardiac[1]. The LP in the magnetocardiograms(MCG) to myocardial infarction (MI), so-called late field (LF), was first detected by Erne et al. in 1983[2]. The LF of the ORS complex was analyzed to indicate

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propensity to life-threatening arrhythmias in patients with MI[3]. Comparing with the electrocardiogram(ECG), the MCG is a non-invasive measurement; the return current does not produce any magnetic field, so the current source can be estimated only by using the current dipole; the magnetic field is different from the current in physical feature, so more information can be obtained[4]. Because there are these advantages above, the MCG has been expected to analyze the high frequency components of the QRS complex. In this study, we used a wavelet equivalent filter to detect the high frequency components of the QRS complex in the three-dimensional(3-D) MCG recorded from the normal subject and the patient with MI. In order to discuss the activities of the heart between the normal subject and the patient with MI, we have presented the isoenergy contour maps to evaluate the spatial energy distribution (SED) of the QRS complex at different scale. We propose to provide new diagnosis method based on the MCG measurement for the patient with MI.

2. Method and meterials

2.1. 3-D second-order gradiometer

A 3-D second-order gradiometer is made of superconducting wire(Nb-Ti-Cu) and is orthogonally wound on a rectangular solid 3×3×6 cm. The characteristic of the 3-D second-order gradiometer is obtained by performing a computer simulation. That is, if a maximum field extreme and a minimum field extreme are obtained in two measurement positions for *Bz* component, there exists an equivalent source(ES) in the middle of two measurement positions; if a maximum field extreme or a minimum field extreme is obtained in a measurement position for *Bx* and *By* components, there exists an ES in the same measurement position[5]. Fig. 1 shows the characteristic of the 3-D second-order gradiometer.

2.2. A wavelet equivalent filter

An algorithm based on the wavelet transform(WT) is developed to construct a wavelet equivalent filter. Wavelet function used in the algorithm is a quadratic spline wavelet with compact support and one vanishing moment. The wavelet equivalent filter forms various frequency band for different scale. First the MCG signal passes through the highpass filter at scale 2^1, then passes through the bandpass filters at scale 2^2, 2^3, 2^4, 2^5 respectively. The signal output at small scale reflects the high frequency components of the MCG signal. The signal output at large scale reflects the low frequency components of the MCG signal[6].

2.3. Isoenergy contour map

In order to discuss electrical activities of the heart between the normal subject and the patient with MI, the SED in different segments of the QRS complex is introduced by.

$$E = \sum_{j=1}^{n} B^2(t_j) \tag{1}$$

Where, t_j is jth sample point, $B(tj)$ is the signal amplitude at jth sample point, and t_1 is the beginning of the QRS complex. The QR, RS, and ST segments of the QRS complex are determined from the referencing ECG signals.

2.4. MCG measurement

The MCG measurement is carried for 4 male normal subjects and 1 male patient with MI using the SQUID magnetometer system mainly consisted of 3-D second-order gradiometer, rf-SQUID, flux locked loop(FLL) circuit, data terminal device and an electro-magnetically shielded room in a magnetic shielded room (MSR). The system noise level measured in the MSR is about 12 fT/(Hz)$^{1/2}$ for *Bx*, *By* components and 15 fT/(Hz)$^{1/2}$ for *Bz* component at 10 Hz. The MCG signal is amplified by the amplifier at high gain 32 dB, and passes through the analog bandpass filter of 0.5 to 300 Hz. The filtered MCG signal is digitized with 1000 Hz sampling frequency. While the output of the data is recorded on the computer hard disk, the ECG signal in the lead II is also recorded on the computer hard disk simultaneously as a timing reference for averaging the MCG signal. Fig. 2 shows the measurement grids (*X*=4cm, *Y*=4cm) of the MCG signal. The measurement positions of 42 points indicated by the circles on the anterior chest wall are set up according to the Saarinen's method[7]. *Bx* component is tangential to the anterior chest wall and from the left to the right. *By* component is tangential to the anterior chest wall and from the head to the foot. *Bz* component is perpendicular to the anterior chest wall and from the back to the front.

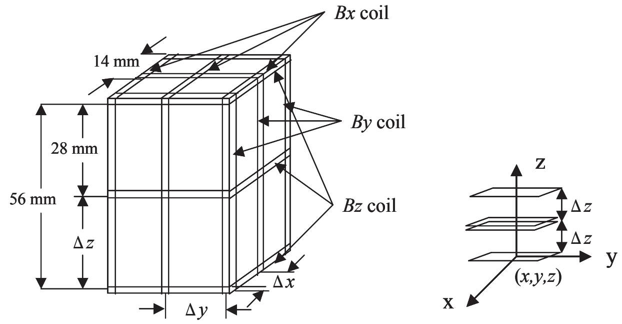

Fig. 1. A 3-D second-order coil.

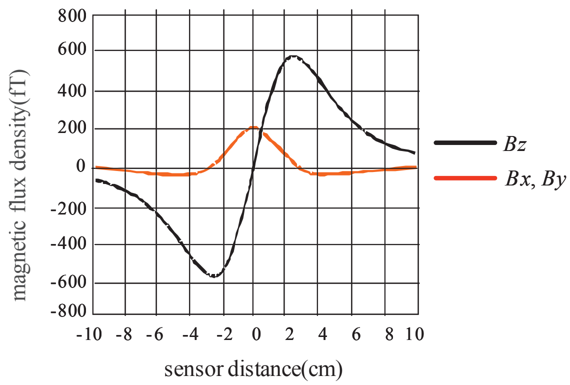

Fig. 2. Characteristic of 3-D second-order gradiometer.

3. Results

We first perform an average of 200 raw data from the record for each measurement position to improve the signal-to-noise ratio (SNR)，then use the wavelet equivalent filter to detect the averaged data. The isoenergy contour maps on the chest wall are obtained from the QR, RS, and ST segments of the QRS complex. Figs. 3 (a), (b) and Figs. 4 (a), (b) represent the isoenergy contour maps at scale 2^3 (35.5 to 110.5 Hz) and 2^5(9.1 to 28.2 Hz) for a normal subject and a patient with MI respectively. Comparing Fig. 3 (a) with Fig. 3 (b), we see that the SED patterns of *Bx*, *By*, *Bz* components are almost all the same for the QR, RS, and ST segments at scale 2^3 and 2^5 for a normal subject. In addition, there are two SED patterns of *Bz* component for the QR, RS, and ST segments. Comparing Fig. 4 (a) with Fig. 4 (b), we see that the SED patterns of *Bx*, *By*, *Bz* components hardly vary for the QR and RS segments at scale 2^3 and 2^5 for a patient with MI. However, they have much more significant change for the ST segment as block lines indicate in Figs. 4 (a) and (b) respectively. In addition, there is one SED pattern of *Bz* component for the QR, RS, and ST segments. The correlation coefficients of the isoenergy contour maps at different scale are calculated to compare the SED quantitatively. We find that the isoenergy contour maps at scale 2^3 have close correlation with the isoenergy contour maps at scale 2^5 for the ST segment of *Bx*, *By*, *Bz* components of a normal subject. The correlation coefficients are *Bx*: 0.924, *By*: 0.963, *Bz*: 0.802 respectively. However, the isoenergy contour maps at scale 2^3 have less close correlation with the isoenergy contour maps at scale 2^5 for the ST segment of *Bx*, *By*, *Bz* components of a patient with MI. The correlation coefficients are *Bx*: 0.094, *By*: 0.413, *Bz*: 0.354 respectively. We also calculate the correlation coefficients for other normal subjects. For all normal subjects, the averaged correlation coefficients were *Bx*: 0.789 ± 0.089, *By*: 0.812 ± 0.123, *Bz*: 0.755 ± 0.064 respectively for the ST segment of *Bx*, *By*, *Bz* components. Normal subjects have closer correlation in the ST segment of the QRS complex than a patient with MI.

The ES can be discussed by using the characteristic of the 3-D second-order gradiometer [5]. As an example, we observe Fig. 3 (a) and Fig. 4 (a) using the characteristic. Fig. 3 (a) shows the maximum energy extreme of *Bx* component at the measurement position C5 for the ST segment. An ES is estimated at the measurement position C5. The maximum energy extreme of *By* component appears at the measurement position C3 for the ST segment. An ES is estimated at the measurement position C3. The maximum energy extremes of *Bz* component appears at the measurement positions D2 and C5 for the ST segment. An ES is estimated at the measurement position C3. Fig. 4 (a) shows the maximum energy extremes of *Bx* component at the measurement positions C3 and C5 for the ST segment. Two ES are estimated at the measurement positions C3 and C5. The maximum energy extreme of *By* component appears at the measurement position C3 for the ST segment. An ES is estimated at the measurement position C3. The SED patterns of *Bz* component show three ES at the measurement position C3, C5 and D4 for the ST segment[8]. Therefore, we can estimate an ES existed at the measurement position C3 for the 3-D MCG. The ES can also be discussed for the QR and RS segments by the same method.

4. Discussion

For biomagnetic measurements, the magnetic field perpendicular to the body surface has widely applied. But there are problems of separating multiple sources overlapping time when cardiac tissues are active. In these cases, the magnetic field perpendicular to the body surface is not helpful in estimating the location and number of source, owing to the lack of a dipole pattern. However, the magnetic field tangential to the body surface wall can provide information about constraint conditions by visual inspection[9]. Therefore, we use the 3-D second-order gradiometer to record the MCG and tried to discuss the ES related to the fragmented activities of the heart by isoenergy contour maps. In some studies, QRS integral maps and fragmentation score maps are used to discuss the spatial distribution of the high frequency components of the QRS complex measured in 1-D MCG (*Bz* component)[10]. The normal subject and the patient represent significantly different the integral values and the score values. But it has seemed that the source localization related to the LF are hardly estimated by these maps.

Being different from the normal subject, the patient with MI represents different the SED pattern in various frequency bands for the ST segment of the QRS complex. That is, the location of the ES varies in various frequency bands. However, the SED pattern of the normal subject is almost the same in various frequency bands for the ST segment of the QRS complex. That is, the location of the ES is constant in various frequency bands. Therefore, the LF in the ST segment may be distinguished by the SED for a patient with MI.

The normal subject and the patient with MI clearly represent different the SED pattern of *Bz* component in the QR, RS, and ST segments. This is because the conduction pathways are uniform or the directions of activation are constant in the normal myocardium, but the conduction pathways are various or the directions of activation change in the ischaemic parts. Therefore, the ischaemic parts cause the perturbation of current flow. Alternatively, the current flow may be disturbed in the ischaemic parts. Subsequently, the strength of the magnetic field will become weaker.

5. Conclusion

In the study, we used the SQUID magnetometer system with 3-D second-order gradiometer to measure the MCG for the normal subjects and the patient with MI. We used a wavelet equivalent filter to detect the high frequency components of the QRS complex for the 3-D MCG. We have been presented the isoenergy contour maps to discuss electrical activities of the heart between the normal subject and the patient with M. It is helpful to evaluate the patient with MI using the isoenergy contour maps of 3-D MCG. However, there are still some problems to be remained in the study. First, it is necessary to discuss the ES related to the fragmented activities of the heart quantitatively for the patient with MI. Second, to prove the clinical application, prospective studies have to be done with a larger number of patients.

Acknowledgements

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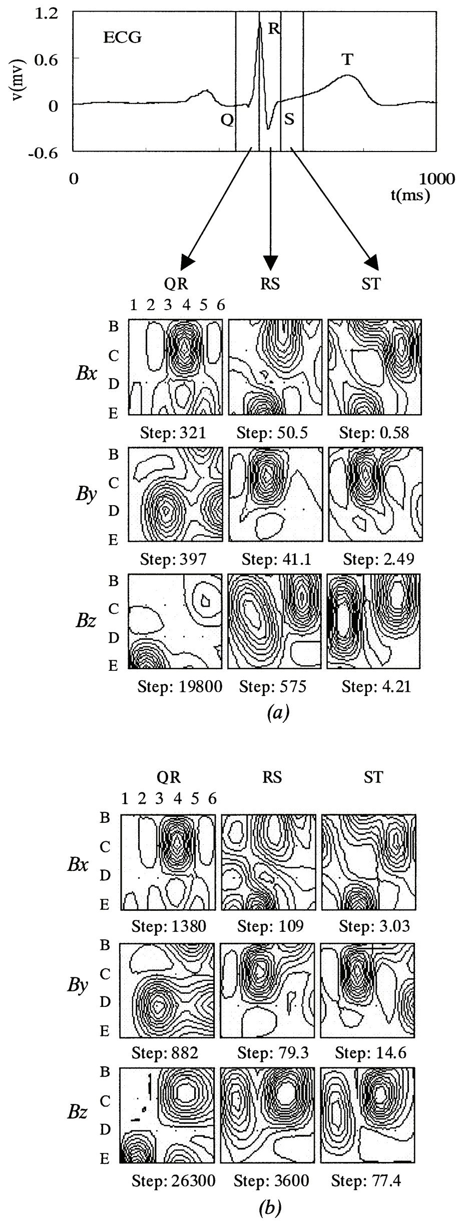

Fig. 3. Isoenergy contour maps of 3-D MCG at different scale for normal subject: (a) Isoenergy contour maps at scale 2^3; (b) Isoenergy contour maps at scale 2^5. Unit of step is square of picotesla ($(pT)^2$).

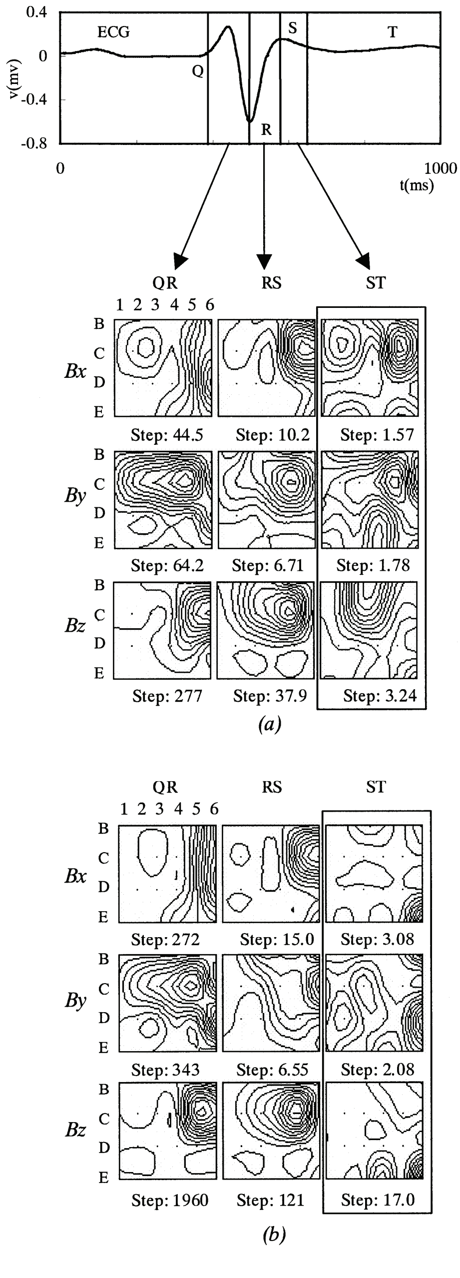

Fig. 4. Isoenergy contour maps of 3-D MCG at different scale for patient with MI: (a) Isoenergy contour maps at scale 2^3 ; (b) Isoenergy contour maps at scale 2^5. Unit of step is square of picotesla ($(pT)^2$). Block lines indicate much more significant change for the ST segment of 3-D MCG at different scale.